Div. VII & IX

THE SO-CALLED INTERNATIONAL ELECTRICAL UNITS.[a]

By Frank A. Wolff.

As one of the most important questions likely to be considered by the St. Louis International Electrical Congress will be that of redefining the fundamental electrical units, it may therefore not be out of place to briefly review the efforts which have thus far been made to bring about international uniformity.

The need of a definite and universal system of electrical units was early recognized, and became a necessity as soon as industrial applications of electricity were made. At first the principal measurements were those of resistance (line resistance, insulation resistance, measurements for the location of faults, etc.). These were expressed in terms of some entirely arbitrary standard, such as the resistance of a given length of an iron or copper wire of given cross section. This naturally led to a great multiplicity of units, none of which ever gained general acceptance.

In 1848 Jacobi pointed out that it would be more satisfactory to adopt as a universal standard the resistance of a certain piece of wire, copies having the same resistance being easily constructed. Jacobi carried this suggestion into practice by sending copies of his standard, since known as "Jacobi's Étalon," to the leading physicists of that period.

In 1860 Werner von Siemens proposed as a standard of resistance the resistance, at 0° C., of a column of mercury of a uniform cross-section of 1 square millimeter and 1 meter in length.

In 1861 a committee composed of the most eminent English physicists was appointed by the British Association to consider the question of standards of electrical resistance. The leading foreign physicists were invited to offer suggestions, and various special investigations of the problems with which the committee was confronted were undertaken by its members.

[a] A paper presented at the International Electrical Congress, St. Louis, 1904.

It was decided that the unit of resistance should be defined in terms of the Gauss-Weber absolute system of electromagnetic units, which had already received such well merited recognition; but since this unit was inconveniently small it was decided to define the practical unit as an integral decimal multiple of the same.

The value of the unit depends upon the units of length, mass, and time adopted as the basis of the system. Those chosen by Gauss and Weber were the millimeter, milligram, and second. In England efforts were being made to establish an absolute system for the definition of all physical units, for which the fundamental units of Weber were of inconvenient magnitude, and for which the centimeter, gram, and second were finally adopted (the c. g. s. system).

The practical unit of resistance in this system was defined as 10^9 c. g. s. electromagnetic units, and while this definition fixes the unit theoretically, it can only be applied in practice by the measurement of some particular resistance in absolute measure. This requires the construction of especially designed apparatus, with which measurements lying within a very limited range may be made; the determination of its instrumental constants most frequently involving tedious mathematical approximations, and the elimination of errors of observation. With all possible precautions the errors of such methods exceed, even to-day, a hundredfold the relative errors in resistance comparisons.

Investigations were therefore made to determine whether the absolute unit of resistance could be accurately defined in terms of the resistance of a definite portion of a definite substance. The electrical properties of alloys and pure metals in the solid and liquid states were studied with this end in view. On account of the excessive influence, on the resistance, of even small quantities of impurities in metals of the highest obtainable purity, and of small variations in the compositions of alloys, the choice was greatly limited. It was found, in addition, that solid metals had to be rejected on account of the marked influenced of physical changes produced by annealing, hardening, drawing, bending, etc.

Mercury, already recommended by Siemens, was therefore the only material to be further considered, but was also rejected for two reasons, viz, the large differences found to exist between coils supposedly adjusted to different German mercurial standards, and differences between a number of mercurial standards constructed by members of the committee.

The committee therefore recommended the alternative method of

constructing material standards adjusted with reference to the absolute unit. In this connection a special form of resistance standard known as the B. A. type was designed, and after an investigation of the constancy of a number of new alloys in addition to many already in use, one containing two parts by weight of silver to one part by weight of platinum was finally selected as best meeting all requirements.

In 1863 and 1864 the values of certain coils were determined in absolute units by one of the methods proposed by Weber, and from these measurements the B. A. unit was derived. A number of copies were issued, gratis, by the association, and in addition arrangements were made for supplying others at a moderate price. The B. A. unit soon gained general acceptance in the English-speaking countries, while the Siemens unit still retained its supremacy on the Continent.

No action was at that time taken by the British association committee to define the units of current and electromotive force further than in terms of the c. g. s. system. The currents to be measured were all relatively small, and were usually measured by means of a tangent galvanometer with a sufficient accuracy. Electromotive forces were seldom measured, and then usually in terms of the Daniell cell. In 1872 Latimer Clark brought to the attention of the committee the superiority of the cell which now bears his name, recommending it as a suitable standard of electromotive force, but no definite action was taken by the committee.

In 1878 it was shown by Prof. H. A. Rowland that the B. A. unit was in error by more than 1 per cent, and soon after the existence of a discrepancy of this magnitude was verified by a number of other investigators.

In 1881 a call was issued by the French Government for an International Electrical Congress, to be held in connection with the first International Electrical Exposition at Paris, for the purpose of adopting definitions of the electrical units which might serve as a basis for legislative enactments. In the meantime a number of mercurial standards had been constructed and had been found to be in satisfactory agreement; moreover, the results of most of the absolute determinations had been referred either directly or indirectly to the Siemens unit.

The Paris Congress, therefore, recommended that the practical electrical units be defined in terms of the units of the c. g. s. system of electromagnetic units, and that the unit of resistance be represented by a column of mercury 1 square millimeter in cross section, at the temperature of 0° C., of a length to be determined by an international

commission appointed for this purpose, as appears in the following resolutions:

RESOLUTIONS OF THE INTERNATIONAL CONGRESS OF ELECTRICIANS, PARIS, 1881.

(1) That the c. g. s. system of electromagnetic units be adopted as the fundamental units.

(2) That the practical units, the ohm and the volt, preserve their previous definitions, 10^9 and 10^8 c. g. s. units, respectively.

(3) That the unit of resistance, the ohm, be represented by a column of mercury 1 square millimeter in cross section at the temperature of 0° C.

(4) That an international commission be charged with the determination, by new experiments, of the length of the mercury column 1 square millimeter in cross section, at a temperature of 0° C., representing the ohm.

(5) That the current produced by a volt in the ohm be called an ampere.

(6) That the quantity of electricity produced by a current of 1 ampere in one second be called a coulomb.

(7) That the unit of capacity be called a farad, which is defined by the condition that a coulomb in a farad raises the potential 1 volt.

The Congress[a] also recommended the employment of the carcel as the standard for photometric comparisons.

The international commission, appointed in accordance with paragraph 4 of the resolutions of the Paris Congress of 1881, met at Paris in 1882, but definite action was deferred until two years later, when the following definitions were unanimously recommended:

The legal ohm is the resistance of a column of mercury 1 square millimeter in cross section and 106 centimeters in length, at the temperature of melting ice.

The ampere is equal to one-tenth of a c. g. s. unit of the electro-magnetic system.

The volt is the electro-motive force which will maintain a current of 1 ampere in a conductor of which the resistance is a legal ohm.

The value adopted for the length of the mercurial column was taken as 106 centimeters, notwithstanding that most of the best results were very close to 106.3; as it was thought advisable to adopt a value known to be true to the nearest centimeter for a period of ten years. On account of this uncertainty, no steps were actually undertaken by the various governments represented.

The conference also adopted as the unit of light of any color the quantity of such light emitted in a perpendicular direction by 1 square centimeter of molten platinum at the temperature of solidification; and as the practical unit of white light the total quantity of light emitted perpendicularly by the same source.

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[a] For the sake of completeness, the recommendations of the various international electrical congresses on photometric standards are included in the summary.

In 1889 a second international congress of electricians was held at Paris, by which the following definitions were adopted:

The joule, the practical unit of energy, is equal to 10^7 c. g. s. units. It is equal to the energy disengaged as heat in one second by a current of 1 ampere flowing through a resistance of 1 ohm.

The practical unit of power is the watt. The watt is equal to 10^7 c. g. s. units, and is the power of 1 joule per second.

The practical unit of self-inductance is the quadrant, which is equal to 10^9 centimeters.

The Congress recommended that the power of machines be expressed in kilowatts instead of in horse-power.

It adopted also, as the photometric standard, the "bougie decimal," defined as one-twentieth of the Violle platinum standard adopted by the Conference of 1884.

The following definitions were also adopted:

The period of an alternating current is the duration of a complete oscillation.

The frequency is the number of periods per second.

The mean intensity is defined as the mean value of the current during a complete period, without reference to its sign.

The effective intensity is the square root of its mean-squared value.

The effective electromotive force is the square root of its mean-squared value.

The apparent resistance is the factor by which the effective current must be multiplied to obtain the effective electromotive force.

The positive pole of a storage cell is that which is connected to the positive pole of a dynamo in charging, and which is the positive pole during its discharge.

In addition, the question of defining and naming practical magnetic units was discussed. The definition proposed for the unit of field intensity was the intensity of a uniform field which would produce an electro-motive force of 1 volt in a conductor 1 centimeter in length normally cutting the lines of force with a velocity of 1 centimeter per second. The name proposed for this unit was the "Gauss;" and as the unit which is equal to 10^8 c. g. s. units does not correspond to field intensities ordinarily dealt with, the micro-Gauss was suggested for ordinary use.

The Weber, defined as 10^8 c. g. s. units, was proposed as the unit of magnetic flux.

No definite action was, however, taken by the Congress on either of these units.

The increased accuracy obtainable by the use of apparatus of improved construction, and by refinements in the methods employed, led to a much closer agreement of the various redeterminations of the absolute electrical units, and their relation to the Siemens unit, the Clark cell, and the electro-chemical equivalent of silver in terms of

which many measurements were made. The rapid development of the electrical industries also called for a redefinition of the units and the legalization of such definitions.

In December, 1890, a committee was appointed by the English Board of Trade to consider what action should be taken by the Board with a view to causing new denominations of standards for the measurements of electricity for use for trade to be made and duly verified. The members of this committee consisted of two representatives each of the Board of Trade, the General Post-Office, the Royal Society, the British Association, and the Institute of Electrical Engineers.

A set of resolutions embodying the proposals which appeared to be desirable were drafted, and copies of the same were submitted to the various interests for criticism. These resolutions also embodied proposals for standards of resistance, current, and electromotive force.

In 1891 a committee was appointed by the American Institute of Electrical Engineers to report on units and standards. The report of the committee, made in June, 1891, which deals mainly with magnetic units, is as follows:

Your committee, considering that authorized and recognized names for four practical electromagnetic units, at present unentitled, are needed by electrical engineers in this as well as in other countries, for dealing conveniently with magnetic circuits in analysis, discussion, and design, recommends to the Institute the four units as appended in detail, of magnetomotive force, reluctance, flux, and flux-density, in the hope that if favorably considered, the Institute may further the endeavors of the next International Electrical Congress toward securing for them universally recognized titles.

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First. *Magnetomotive force;* or difference of magnetic potential.

Simple definition.—The analogue in a magnetic circuit of voltage in an electric circuit.

Strict definition.—The magnetomotive force in a magnetic circuit is 4π multiplied by the flow of current linked with that circuit.

The magnetomotive force between two points connected by a line is the line integral of magnetic force along that line. Difference of magnetic potential constitutes magnetomotive force.

Electromagnetic dimensional formula, $L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$.

The absolute unit of m. m. f. is $\frac{1}{4\pi}\times$ unit current of one turn.

The practical unit is $\frac{1}{4\pi}\times$ ampere of one turn, or one-tenth of the absolute unit—i. e., 0.0796 ampere-turns give the unit. The prefix kilo would perhaps be occasionally used for practical applications.

Second. *Magnetic flux.*

Simple definition.—Total number of lines of force or total field.

Strict definition.—The magnetic flux through a surface bounded by a closed curve is the surface integral of magnetic induction taken over the bounded surface, and when produced by a current is also equal to the line integral of the vector potential of the current taken around the boundary.

The uniform and unit time rate of change in flux through a closed magnetic circuit establishes unit electromotive force in the circuit.

Electromagnetic dimensional formula, $L^{\frac{3}{2}}M^{\frac{1}{2}}T^{-1}$.

The absolute unit is 1 c. g. s. line of induction.

The practical unit is 10^8 c. g. s. lines.

Fluxes range in present practical work from 100 to 100,000,000 c. g. s. lines, and the working units would perhaps prefix milli- and micro-.

Third. *Magnetic intensity*, or induction density.

Simple definition.—Flux per square centimeter.

Strict definition.—The induction density at a point within an element of surface is the surface differential of the flux at that point.

Electromagnetic dimensional formula, $L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}$.

Absolute unit, 1 c. g. s. line per square centimeter.

Practical unit, 10^8 c. g. s. lines per square centimeter.

In practice, excluding the earth's field, intensities range from 100 to 20,000 lines per square centimeter, and the working unit would perhaps have the prefix milli- or micro-.

Fourth. *Magnetic reluctance.*

Definition.—Unit reluctance in a magnetic circuit permits unit magnetic flux to traverse it under the action of unit magnetomotive force.

Dimensional formula, $L^{-1} M^0 T^0$.

The practical unit is 10^{-9} the absolute unit.

Reluctances vary in present practical work from 100,000 to 100,000,000 of these practical units, so that the working unit would perhaps employ the prefix mega-.

There were considerable differences of opinion manifested in the discussion following the presentation of the report, and definite action thereon was postponed.

At the Frankfort International Electrical Congress, in September, 1891, the question of naming and defining the magnetic units was brought up. The names Gauss and Weber, for field intensity and flux, respectively appeared to meet with general approval, but there was considerable disagreement as to what their numerical values should be, 10^8 being apparently preferred for both.

Owing to the limited time allowed for consideration, no definite action was taken.

In connection with the British Association meeting in Edinburgh, in 1892, a conference was held, attended by Helmholtz, Guillaume, Carhart, and others, to discuss the Board of Trade report which was submitted at the meeting. It was resolved to adopt for the length of the mercurial column 106.3 centimeters and to express the mass of the column of constant cross-section instead of the cross-sectional area of 1 square millimeter. Final action was deferred to await the decision of the Chicago International Electrical Congress, arrangements for which had then been made.

This Congress, to which the various governments were invited to send delegates, met in 1893. The Governments represented were

United States, Great Britain, France, Italy, Germany, Mexico, Austria, Switzerland, Sweden, and British North America. Professor von Helmholtz was made honorary president of the Congress, and Prof. H. A. Rowland president of the Chamber of Delegates, composed of the official delegates of the various Governments represented. After six days' deliberation the following resolutions were adopted:

RESOLUTIONS OF THE INTERNATIONAL ELECTRICAL CONGRESS, CHICAGO, 1893.

Resolved, That the several Governments represented by the delegates of this International Congress of Electricians be, and they are hereby, recommended to formally adopt as legal units of electrical measure the following:

Ohm. As a unit of resistance, the *international ohm*, which is based upon the ohm equal to 10^9 units of resistance of the c. g. s. system of electro magnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grammes in mass, of a constant cross-sectional area and of the length of 106.3 centimeters.

Ampere. As a unit of current, the *international ampere*, which is one-tenth of the unit of current of the c. g. s. system of electromagnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accordance with accompanying specifications, deposits silver at the rate of 0.001118 of a gramme per second.

Volt. As a unit of electromotive force, the *international volt*, which is the electromotive force that, steadily applied to a conductor whose resistance is 1 international ohm, will produce a current of 1 international ampere, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the electromotive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C., and prepared in the manner described in the accompanying specifications.

Coulomb. As a unit of quantity, the *international coulomb*, which is the quantity of electricity transferred by a current of 1 international ampere in one second.

Farad. As a unit of capacity, the *international farad*, which is the capacity of a condenser charged to a potential of 1 international volt by 1 international coulomb of electricity.

Joule. As a unit of work, the *joule*, which is equal to 10^7 units of work in the c. g. s. system and which is represented sufficiently well for practical use by the energy expended in one second by an international ampere in an international ohm.

Watt. As a unit of power, the *watt*, which is equal to 10^7 units of power in the c. g. s. system, and which is represented sufficiently well for practical use by work done at the rate of 1 joule per second.

Henry. As the unit of induction, the *henry*, which is the induction in a circuit when the electro-motive force induced in this circuit is 1 international volt, while the inducing current varies at the rate of 1 ampere per second.

SPECIFICATIONS.

In the following specifications the term silver voltameter means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment, and by noting this time, the time average of the current, or if the current has been kept constant, the current itself can be deduced.

In employing the silver voltameter to measure currents of about 1 ampere, the following arrangements should be adopted:

The kathode on which the silver is to be deposited should take the form of a platinum bowl not less than 10 cm in diameter and from 4 to 5 cm in depth.

The anode should be a plate of pure silver some 30 cm^2 in area and 2 or 3 mm in thickness.

This is supported horizontally in the liquid near the top of the solution by a platinum wire passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling onto the kathode, the anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

SPECIFICATIONS FOR THE CLARK CELL.

A committee, consisting of Messrs. von Helmholtz, Ayrton, and Carhart, was appointed to prepare specifications for the Clark cell. (Owing to the death of Von Helmholtz no report was ever made by this committee.)

Magnetic units.

A motion was made and carried that for magnetic units the c. g. s. system be commended, and that for the present no names be given to these units.

Photometric standards.

A resolution was adopted as follows:

Resolved, That this committee while recognizing the great progress realized in the standard lamp of Von Heffner-Alteneck and the very important researches made at the Reichsanstalt, also recognizes that other standards have been proposed and are now being tried, and that there are serious objections to every kind of standard in

which an open flame is employed. It is, therefore, unable to recommend the adoption at the present time of either the Von Heffner lamp or the pentane lamp, but recommends that all nations be invited to make researches in common on well-defined practical standards and on the convenient realization of the absolute unit.

In March, 1900, the following resolution was adopted by the American Institute of Electrical Engineers:

Moved, That the committee on units and standards be requested to investigate and report at the ensuing meeting in regard to the advisability of the following:

1. The giving of names to the absolute units of the electrostatic and electromagnetic systems.
2. The denotations, by means of prefixes, of multiples of such units.
3. The rationalization of the present system by means of taking the absolute unit of magnetism as equal to the present magnetic line, and the absolute unit of difference of magnetic potential as equal to the present absolute unit of current-turn.
4. The advisability of taking up any or all of the above matters at the Congress to be held in Paris this year.

In May, 1900, the following report of the committee was adopted by the Institute:

1. We consider that there is need for names for the absolute c. g. s. units in the electrostatic and the electromagnetic systems; also for suitable prefixes to denote decimal multiples and submultiples of these units in supplement and addition to those already in common use.
2. That the International Electrical Congress convening this year at Paris should be urged to bestow the above-mentioned names and create said decimal prefixes.
3. That much advantage would accrue to a universal "rationalization" of electric and magnetic units, and that the Congress be requested to consider the means and advisability of such "rationalization."
4. That we recommend that the whole subject should be brought up as a topic for general discussion at the approaching general meeting of the Institute in Philadelphia.

(Signed) F. B. CROCKER.
W. E. GEYER.
G. A. HAMILTON.
W. D. WEAVER.
A. E. KENNELLY, *Chairman.*

PARIS CONGRESS, 1900.

The last official Congress was held at Paris in August, 1900.

A committee of Section 1, to consider questions in reference to the units, reported as follows:

The committee will only take into consideration propositions not involving modifications of the decisions of previous congresses.

The committee believes that there is no actual need of giving names to all the electro-magnetic units.

However, owing to the employment, in practice, of apparatus giving directly field intensities in c. g. s. units, the committee recommends giving the name "Gauss" to this c. g. s. unit.

The committee recommends giving to the unit of magnetic flux, the value of which is subsequently to be fixed, the name "Maxwell."

The report adopted by the Section, after a spirited discussion, was as follows:

1. The Section recommends giving the name "Gauss" to the c. g. s. unit of magnetic field intensity.

2. The Section recommends giving the name "Maxwell" to the c. g. s. unit of magnetic flux.

These units were given an international character and standing by their adoption at the general meeting of the official delegates of the various governments, after a stormy debate.

The Legalization of the Electrical Units by the Various Governments.

Notwithstanding that the resolutions of the Chicago Congress were adopted with practical unanimity, and might, therefore, have been considered as in a sense binding on the various governments, up to this date only six governments, United States, Great Britain, Canada, Germany, Austria, and France, have legislated on this subject, and only a few of these have acted strictly in accordance with the resolutions of the Chicago Congress.[a]

Discussion of Legislation.

Strictly speaking, no two countries have defined the electrical units in the same way. This naturally suggests that there must be good and sufficient reasons, which may in part be traced to the insufficiency of the Chicago definitions.

(1) It is evident that all three of the units should not be defined in terms of concrete standards, connected as they are by Ohm's law so that only two of the three are independent, and hence the third should be defined in terms of the other two.

(2) The two units adopted as fundamental should be defined only in terms of concrete standards, and not in terms of the absolute units.

(3) The specifications for the silver voltameter were shown to be inadequate.

(4) Redeterminations of the electro-motive force of the Clark cell at 15° C. in absolute measure indicated that this value was nearer 1.433 volts than 1.434 volts.

However, the variations introduced in the definitions by some of the governments lead to confusion and are in violation of the principles laid down at the Chicago Congress.

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[a] For a copy of the laws see Appendix.

THE UNIT OF RESISTANCE.

Taking the fundamental units up in turn, it will be found that the unit of resistance legalized by the United States, Germany, France, and Canada, and the definitions in the proposed Belgian and Swiss laws, are essentially the same as those adopted at Chicago, differing only in that no reference is made to the unit of resistance being based on 10^9 c. g. s. units in case of the German and French laws and in the proposed Swiss and Belgian laws. In fact, it must be admitted that this statement may be regarded as superfluous.

Austria.

In Austria, on the other hand, the unit of resistance is defined as 10^9 c. g. s. units of the electro-magnetic system, which "*for practical purposes* is to be considered equal to the resistance offered at the temperature of melting ice by a column of mercury 106.3 centimeters in length and having a mass of 14.4521 grams." The uniformity of cross section is, curiously, not specified.

England.

In England, finally, the ohm is defined both as *having the value* of 10^9 in terms of the centimeter and the second of time, *and as being represented* by "the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice 14.4521 grams in mass of a constant cross-sectional area and of a length of 106.3 centimeters." In addition, a distinction is made between the *unit* of resistance and the *standard* of resistance, and for the latter purpose a particular platinum-silver coil preserved at the Board of Trade Electrical Standardizing Laboratory, in London, and adjusted to represent the unit on an assumed relation between the standards of the British Association and the mercurial unit, is legalized.

It will thus be seen that the unit of resistance has been defined—

(1) In terms of the absolute c. g. s. unit.

(2) In terms of the mercurial column.

(3) In terms of the resistance of a particular coil.

(4) In terms of combinations of the above.

The objections to the first method have been recognized as long as the subject has been under discussion. For, while the unit is theoretically fixed, resort must in practice be had to material standards, in the absolute measurement of which, errors amounting to at least 0.01 per cent are introduced. Errors several times as great are even met with in different series of observations with the same apparatus, and the differences of the results obtained by different methods may differ still more.

To overcome this objection a suggestion was made in 1893, by Profs. W. E. Ayrton and A. V. Jones, that the unit of resistance be defined

in terms of a particular Lorenz apparatus preserved in a National Physical Laboratory, but even then an uncertainty of at least 0.01 per cent would remain if this practice were adopted by a single government, whereas its general introduction would certainly introduce greater differences.

Another objection to this method lies in the limited range within which accurate measurements of resistance may be made with a given apparatus, so that in practice the measurements would have to be referred to material standards the constancy of which might from time to time be checked to within the above stated limit of accuracy.

Notwithstanding these objections we find that a number of governments have defined the unit of resistance in terms of the absolute unit, indicating that the above principles are not fully appreciated.

The accuracy with which resistance comparisons can be made has for a long time far exceeded the above limits, and the need of an accurate standard, reproducible at any time and at any place to a higher degree of accuracy, has been recognized, as this would enable measurements the world over to be expressed in terms of the *same unit*—a result of much greater importance than in *absolute measure*, with its limited accuracy. In the definition of the concrete standard it is only necessary to assume for it a value in accordance with the best absolute measurements. This once done with a sufficient approximation, the definition of the concrete standard need not be modified.

The meter was originally intended to represent the $\frac{1}{10,000,000}$ part of the earth's quadrant; but in the actual construction errors of measurement were introduced, which will, however, not affect the *international* meter defined in terms of a particular platinum-iridium bar, of which accurate copies exist the world over, and to which all linear measurements are referred. In a similar manner, the kilogram was intended to represent the mass of a cubic decimeter of water at the temperature of its maximum density; but the *international* kilogram is the mass of a particular cylinder of platinum-iridium, to which all measurements of mass are referred.

It has, therefore, been generally recognized that *reproducibility* should be the first requirement for any international standard, and this qualification is fulfilled to an eminent degree by the mercurial unit, as defined by the Chicago Congress.

When this definition was adopted it was generally assumed that such mercurial standards would be constructed by the various governments represented; but this has been done by only two—Germany and England—each of which is provided with an institution equipped

to undertake this task. The construction of primary mecurial standards is also to be undertaken by the Bureau of Standards, more recently organized, and no doubt by other institutions.

The mercurial standards at the Reichsanstalt agree with one another to within a few parts in 100,000, as do those of the English National Physical Laboratory; and it is, in addition, most gratifying to know that the standards of the two institutions agree with each other almost equally well.

There is, however, one criticism which might still be made of the definition of the unit of resistance in terms of the mercurial unit. Some form of terminal must be applied to the tube to connect it to the circuit containing the resistance standard with which it is to be compared. The method used at the Reichsanstalt consists in employing spherical bulbs, each provided with a current and potential lead, which necessitates the application of a correction, the value of which can be calculated approximately, as Lord Rayleigh has shown, or may be experimentally determined. Unfortunately, the value experimentally found is less than the minimum limit according to Lord Rayleigh's calculations, so that a different result will be obtained according to the correction factor employed.

In addition, there is another method, which might and has been used, of applying potential terminals to the extremities of the tube, which is provided with prolongations previously continuous with the same. This method also introduces a correction the value of which would depend upon a number of conditions.

In any case, however, this source of uncertainty, although slight, could be eliminated by specifying the approximate cross-section or length of the tube representing the unit, the nature of the terminals, and the magnitude of the correction factor to be applied.

THE UNIT OF CURRENT.

The Chicago definition of the ampere as one-tenth of the c. g. s. unit has been followed almost verbatim by the United States, Canada, France, and Austria, and the specifications for the silver voltameter are essentially the same except in Austria, where no specifications have been legalized.

In Germany the ampere is simply defined in terms of the electrochemical equivalent of silver, and in addition the specifications for the silver voltameter are considerably modified.

The proposed Swiss law has been copied from the German law.

The Belgian law differs from the German law only in that the ampere is defined, not as being equal to, but as being sufficiently well

represented for practical purposes by "the intensity of a constant current which precipitates in one second 0.001118 grams of silver from an aqueous solution of silver nitrate."

In England it is defined both as one-tenth of a c. g. s. unit, and *as being represented by* "the unvarying electric current which, when passed through a solution of nitrate of silver in water in accordance with the specification appended hereto and marked 'A,' deposits silver at the rate of 0.001118 of a gram per second." In addition, a distinction is made between the *unit* of current and the *standard* of current, the latter being defined in terms of a particular standard ampere balance preserved in the Board of Trade Electrical Standardizing Laboratory.

It will thus be seen that the ampere is defined in three distinct ways, and in some cases the same country has defined it in two or more ways. As has been pointed out, if the ampere is selected as the second fundamental unit it should not be defined in terms of the absolute unit, but simply in terms of the silver voltameter, for which, according to a number of investigations since 1893, the specifications are insufficient, as differences amounting to more than 0.1 per cent may be obtained. The cause of these variations was first shown by Kahle at the Reichsanstalt to be due to secondary reactions in the voltameter, as indicated by differences when freshly prepared silver-nitrate solutions and solutions previously used are employed. Richards, Collins, and Heimrod have traced this influence to the secondary reactions at the anode, and have shown that they may be reduced and possibly eliminated by surrounding the same with a porus cup in which the solution is always kept at a lower level than outside, to prevent diffusion.

This subject has been further investigated by Dr. K. E. Guthe, of the Bureau of Standards, who confirmed the results of Richards, Collins, and Heimrod, and who constructed a more convenient form of voltameter by using a large anode in addition to a porous cup, the best results being obtained with a silver plate in contact with granulated silver. Variations in the results have been attributed to the filter paper, with which in the older forms the anode is surrounded. That the silver nitrate acts upon the paper can not be questioned, but its influence on the solution can hardly explain the results.

The filter paper, however, fails to prevent the secondary products formed at the anode, the exact nature of which has not been established, from reaching the cathode, while the porous cup prevents it almost entirely. The results obtainable with the Richards and the modified forms seem to be reproducible to within about 1 part in

20,000, so that unit current may be defined in terms of the electrochemical equivalent of silver to within this order of accuracy.

The two arguments most frequently advanced in favor of concretely defining the ampere, instead of the volt, are as follows:

(1) According to Faraday's laws of electrolysis, the amount of a given metal deposited in a given time by a given current is constant. As seen above, complications are introduced by secondary reactions at the electrodes, which vary with the metal and the current density employed, making it necessary to specify the form and manner of employment of the voltameter to obtain constant results.

(2) Current intensity can be determined in absolute measure directly by the electro-dynamometer, while electromotive force can only be measured directly in absolute units of the electrostatic system, and the accuracy with which the results can be reduced to electromagnetic units depends upon the accuracy with which "v," the ratio of the units of the two systems or the velocity of light is known and this is uncertain by possibly as much as 1 part in 1,000.

While this argument would have considerable weight if the fundamental units were to be defined in terms of their absolute values, a practice which, as pointed out above, should be abandoned entirely, it has little bearing on the definition of either current or electromotive force in terms of a concrete standard, for which a value may be adopted which agrees with the best results of absolute current measurement.

The objections which might be urged against defining the ampere, instead of the volt, are as follows:

(1) With a given silver voltameter the range is limited and only currents lying within certain narrow limits can be accurately measured.

(2) Enough time must be allowed for the deposit of at least several grams of silver, so that accurate weighings may be made.

(3) The duration of the experiment must be at least one-half hour, in order that the time may be accurately measured.

(4) During the experiment the current must be kept constant by continuous regulation, or the variations from its mean value must be determined at frequent intervals, so that the average value may be calculated.

(5) Tedious double weighings must be made to determine the amount of silver deposited.

(6) The result finally obtained applies to the average value of the current employed during the experiment and can not be utilized for the accurate measurement of other currents except by reference to a standard cell and a standard resistance, or to some form of apparatus

for current measurement, such as the electrodynamo meter, in which case the accuracy is not as great as that obtained by direct reference to a standard cell.

UNIT OF ELECTROMOTIVE FORCE.

The definition of the volt adopted at Chicago has been legalized almost verbatim by the United States, Canada, and France. In Germany and Austria it is defined simply in terms of the ohm and ampere, as is also the case in the proposed Swiss and Belgian laws.

In England the volt is defined as 10^8 c. g. s. units, in terms of the ohm and ampere, and in terms of the Clark cell. In addition, a distinction is made between the *unit* of electromotive force and the *standard* of electromotive force, the latter being defined as the $\frac{1}{100}$ part of the pressure producing a certain deflection of a Kelvin electrostatic voltmeter of the multicellular type preserved at the Electrical Standardizing Laboratory of the Board of Trade.

Here again the definitions legalized differ considerably. Of the various definitions only two need be considered—that in terms of the ohm and ampere, if these units are taken as fundamental, and the definition in terms of the standard cell, if the ohm and volt are taken as the fundamental units.

The arguments in favor of the latter alternative may be briefly summarized as follows:

(1) The facility with which *any* voltage may be directly measured in terms of the standard cell by the potentiometer.

(2) The accuracy with which such measurements may be made, which is practically limited only by the accuracy with which resistance is measurable and by the reproducibility of the cell.

(3) The accuracy with which the standard cell can be reproduced, which even to-day exceeds all practical requirements and which may be still further increased by specifying more precisely the manner of purification and preparation of the materials employed, etc.

(4) The resulting definition of the ampere in terms of the ohm and volt, which corresponds to the actual method employed in precision measurements of current intensity by the potentiometer method.

(5) The facility and accuracy with which any current may be thus measured.

These considerations have led to the adoption of the Clark cell in Germany as the practical standard of electromotive force, notwithstanding that the ampere is legally defined in that country in terms of the electrochemical equivalent of silver and the volt in terms of the ohm and ampere.

For the electromotive force of the Clark cell, the value 1.4328 volts was adopted in Germany as equivalent to the legalized definitions of the ohm and ampere.

In the United States the legalized value of the electromotive force of the Clark cell is 1.434 volts at 15° C. Either this value had to be taken or that of the electrochemical equivalent of silver. The latter seemed less desirable, owing to the insufficiency of the legalized specifications for the silver voltameter and the large variations reported.

The specifications for the Clark cell legalized in the United States were drawn up by the National Academy of Sciences, and refer to the λ type; while those in England, Canada, and France are essentially those drawn up by the Board of Trade committee and refer to the Board of Trade type.

STANDARD CELLS.

Of the standard cells proposed, only the Clark and Weston cells are to be considered at present. In the former the electrodes consist of zinc amalgam covered with a layer of zinc sulphate crystals and pure mercury in contact with a paste of mercurous sulphate, zinc sulphate crystals, and metallic mercury, the electrolyte being a saturated aqueous solution of zinc sulphate and mercurous sulphate.

In the Weston cell the electrodes consist of cadmium amalgam covered with a layer of cadmium sulphate crystals, and pure mercury in contact with a paste of mercurous sulphate, cadmium sulphate crystals, and metallic mercury, the electrolyte being a concentrated aqueous solution of cadmium sulphate and mercurous sulphate.

The investigations thus far reported indicate that differences between individual cells of either type, set up from materials obtained from various sources and at various times, agree with each other to within 0.0002 volts, corresponding to a slight advantage in favor of the Clark cell on account of its higher electromotive force. The constancy and reproducibility of both types have also been established by the constancy of the ratio between them.

While sharing with the Clark cell these most essential qualities, the Weston cell has a number of marked advantages.

(1) The higher temperature coefficient of the Clark cell is a serious obstacle to measurements of the highest precision, while that of the Weston cell at ordinary temperatures is less than one-twentieth as great, so that errors due to temperature uncertainties are correspondingly reduced.

(2) Clark cells are subject, particularly when a number of years old, to large hysteresis effects attending temperature variations. In the Weston cell the error due to this cause can only amount to a small

fraction of that in the Clark cell, owing to the relatively slight influence of temperature on the solubility of the cadmium sulphate.

(3) The average life of Clark cells is quite short, owing to the tendency of the cell to crack at the point where the platinum terminal is fused into the amalgam limb. This objection might be obviated by suitable modifications in the construction, as have been suggested, but not without introducing some complication. No such tendency has been observed with Weston cells.

(4) In Clark cells a layer of gas is formed at the amalgam surface, even when carefully neutralized solutions are employed, which may interrupt the circuit, thus rendering the cell useless. In the Weston cell no gas is, apparently, formed.

Owing to these marked advantages, the Weston cell is certain to displace the Clark cell in the laboratory, and no doubt many advocates of the adoption of the former as the standard of electromotive force will be found among the delegates to the St. Louis International Congress.

SPECIFICATIONS FOR THE STANDARD CELL.

If either the Clark or the Weston cell be adopted as the standard of electromotive force, the specifications will have to be to some extent redrawn if the highest accuracy of reproduction is sought, as the differences between individual cells set up with different materials at present far exceed the relative errors made in current and electromotive force measurements by the potentiometer method. It, therefore, seems desirable, as stated above, to specify more precisely the methods of purification and preparation of the materials employed.

Fortunately, the metals entering into the composition of Clark and Weston cells,—mercury, zinc, and cadmium,—are among the few which can be obtained by special methods so pure that the foreign metals in them do not exceed more than 0.001 per cent. Zinc sulphate and cadmium sulphate can be obtained from the specially purified metals and pure sulphuric acid. Even considerable quantities of the impurities usually accompanying the above materials, when purchased as "chemically pure," exert a relatively small and even insignificant influence on the electromotive force of the cell. In defining the standard cell, however, the method of preparation or purification and the degree of purity of the materials should certainly be specified.

The principal source of variation of the standard cell has lately been shown to be due to differences in the electromotive properties of the mercurous sulphate. The "chemically pure" mercurous sulphate of commerce contains, besides nitrates, etc., basic mercurous sulphate,

mercuric sulphate, basic mercuric sulphate, and possibly sulphites. According to the Chicago specifications, since generally adopted, the mercurous sulphate is washed a number of times with distilled water, which converts the mercuric sulphate into basic mercuric sulphate, which is not removed. Moreover, the water hydrolizes the mercurous sulphate, converting part of it into basic mercurous sulphate. Both these materials having a definite solubility in the zinc sulphate and cadmium sulphate solutions, must exert an influence on the electromotive force of the cell. The basic mercurous sulphate, when present in excess, will exert an influence on the electromotive force, while the basic mercuric sulphate is gradually decomposed and eliminated, thus introducing a variable factor.

Pure mercurous sulphate, however, may be obtained from pure mercury and sulphuric acid, by an electrolytic method independently devised by Carhart and Hulett, and the author, and the results already obtained indicate that the agreement of cells set up with this material is within a few parts in 100,000, but further work is desirable.

It is, therefore, most important, if the unit of electromotive force is defined in terms of the standard cell, to specify the manner in which this material is to be prepared, and to modify some of the specifications relating to its treatment.

Besides new specifications for the ampere or volt in terms of the electrochemical equivalent of silver, or the electromotive force of some particular standard cell, respectively, it will be necessary to adopt a new value for one of these constants. This may be based either on the absolute determinations already made, applying to the accepted values, corrections determined by the modifications in the specifications which may be adopted and a correction in order to bring the unit into closer agreement with the absolute value upon which it is based, or by new absolute determinations. If the latter alternative is decided upon, considerable delay would probably ensue, and in addition, not much could be gained, owing to the relatively large errors of all absolute measurements and the differences likely to be found between the results obtained by different investigators using different methods and apparatus.

Two determinations of the electromotive force of the Clark cell in absolute measure, made by Kahle at the Reichsanstalt, and by Carhart and Guthe, indicate that the value adopted by the Chicago Congress, 1.434 volts, is too large by about 1 millivolt; and in addition, several redeterminations of the mechanical equivalent of heat in electrical units give values for the latter which can only be brought into accord with the values determined by the direct mechanical methods if the

electromotive force of the Clark cell be taken as 1.433. If this value be adopted for the Clark cell, or the equivalent value for the Weston cell, the international units, would be defined with a quite sufficient absolute accuracy, as the above value is most probably known to at least 1 part in 2,000, and as at the present time a much higher absolute accuracy can hardly be predicted. It seems, on the other hand, that the main question is to define the international units with the prime object of *reproducibility* to the highest order of accuracy, and it is hoped that in this an accuracy of a few parts in 100,000 will be realized.

DERIVED UNITS.

It will be generally agreed that the units of capacity, inductance, power, energy, and any others that the St. Louis Congress may decide to include, should be defined in terms of the definitions adopted for the fundamental units.

The joule and watt have, however, been defined in terms of the c. g. s. units by some countries, and objections will probably be raised to defining them in terms of the electrical units. Such objections could be met by making a distinction between the absolute joule and international joule, and the absolute watt and the international watt, a distinction already used to some extent in distinguishing between the absolute units and the international electrical units. As the system becomes established the designation international will gradually be dropped. Moreover, if the values adopted for the international units agree with the absolute values upon which they are based to within even 1 part in 1,000, as will be the case, the objections will be mainly theoretical, as all practical requirements will be met.

MAGNETIC UNITS.

The only official action thus far taken in defining the magnetic units is that of the Paris Congress of 1900 by which the c. g. s. units of magnetic field intensity and magnetic flux were adopted, the names Gauss and Maxwell being assigned to them.

The St. Louis Congress may, however, consider the adoption of additional units of magnetomotive force and magnetic reluctance and the definition of all the magnetic units in harmony with the practical system of electromagnetic units. None of the units, either of the practical or c. g. s. system, is of a convenient magnitude, but this should, of course, not determine the choice. If there is any need of decimal multiples or submultiples, these can be supplied by the use of a suitable prefix.

It must, however, be emphasized that the definition of the magnetic units directly in terms of the c. g. s. units or in terms of multiples or submultiples of the same is open to the serious objection that it would lead to an inconsistency if the fundamental electrical units are defined in terms of concrete standards and that it would be equivalent to a redefinition of these electrical units, interconnected as they are with the magnetic units in terms of the units of the c. g. s. system.

This can only be avoided by defining the magnetic units in terms of the fundamental international electrical units—the ohm, volt, and ampere—and any resulting ambiguity might be removed by designating the units thus defined as international magnetic units.

APPENDIX.

LEGAL DEFINITION OF THE ELECTRICAL UNITS IN THE UNITED STATES.

[Act approved July 12, 1894.]

Be it enacted, &c., That from and after the passage of this act the legal units of electrical measure in the United States shall be as follows:

First. The unit of resistance shall be what is known as the international ohm, which is *substantially equal* to one thousand million units of resistance of the centimeter-gram-second system of electromagnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice fourteen and four thousand five hundred and twenty-one ten-thousandths gram in mass, of a constant cross-sectional area, and of the length of one hundred and six and three-tenths centimeters.

Ohm.

Second. The unit of current shall be what is known as the international ampere, which is one-tenth of the unit of current of the centimeter-gram-second system of electro-magnetic units, and *is the practical equivalent* of the unvarying current, which, when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of one thousand one hundred and eighteen millionths of a gram per second.

Ampere.

Third. The unit of electro-motive force shall be what is known as the international volt, which is the electro-motive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of an international ampere, and is *practically equivalent* to one thousand fourteen hundred and thirty-fourths of the electro-motive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of fifteen degrees centigrade, and prepared in the manner described in the standard specifications.

Volt.

Fourth. The unit of quantity shall be what is known as the international coulomb, which is the quantity of electricity transferred by a current of one international ampere in one second.

Coulomb.

Fifth. The unit of capacity shall be what is known as the international farad, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity.

Farad.

Sixth. The unit of work shall be the joule, which is equal to ten million units of work in the centimer-gram-second system, and which is practically equivalent to the energy expended in one second by an international ampere in an international ohm.

Joule.

Seventh. The unit of power shall be the watt, which is equal to ten million units of power in the centimeter-gram-second system, and which is practically equivalent to the work done at the rate of one joule per second.

Watt.

Henry.

Eighth. The unit of induction shall be the henry, which is the induction in a circuit when the electro-motive force induced in this circuit is one international volt while the inducing current varies at the rate of one ampere per second.

SEC. 2. That it shall be the duty of the National Academy of Sciences to prescribe and publish, as soon as possible after the passage of this act, such specifications of detail as shall be necessary for the practical application of the definitions of the ampere and volt hereinbefore given, and such specifications shall be the standard specifications herein mentioned.

SPECIFICATIONS.

In conformity with section 2 of the above act, the National Academy of Sciences, on February 9, 1895, accepted and unanimously adopted the following report:

REPORT.

In the preparation of this report, in order to have the specifications accord with international usage, free use has been made of the English Government specifications and of certain papers prepared by Dr. K. Kahle, of Germany, and Prof. H. S. Carhart, of this country.

SPECIFICATIONS FOR THE PRACTICAL APPLICATION OF THE DEFINITIONS OF THE AMPERE AND VOLT.

SPECIFICATION A.—*The ampere.*

In employing the silver voltameter to measure currents of about 1 ampere, the following arrangements shall be adopted:

The kathode on which the silver is to be deposited shall take the form of a platinum bowl not less than 10 centimeters in diameter, and from 4 to 5 centimeters in depth.

The anode shall be a disk or plate of pure silver some 30 square centimeters in area and 2 or 3 millimeters in thickness.

This shall be supported horizontally in the liquid near the top of the solution by a *silver rod riveted through its center.* To prevent the disintegrated silver which is formed on the anode from falling upon the kathode, the anode shall be wrapped around with pure filter paper, secured at the back by suitable folding.

The liquid shall consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

Method of making a measurement.—The platinum bowl is to be washed consecutively with nitric acid, distilled water, and absolute alcohol; it is then to be dried at 160° C., and left to cool in a desiccator. When thoroughly cool it is to be weighed carefully.

It is to be nearly filled with the solution and connected to the rest of the circuit by being placed on a clean insulated copper support to which a binding screw is attached.

The anode is then to be immersed in the solution so as to be well covered by it and supported in that position; the connections to the rest of the circuit are then to be made.

Contact is to be made at the key, noting the time. The current is to be allowed to pass for not less than half an hour, and the time of breaking contact observed.

The solution is now to be removed from the bowl and the deposit washed with distilled water and left to soak for at least six hours. It is then to be rinsed successively with distilled water and absolute alcohol and dried in a hot-air bath at a temperature of about 160° C. After cooling in a desiccator it is to be weighed again. The gain in mass gives the silver deposited.

To find the time average of the current in amperes, this mass, expressed in grams, must be divided by the number of seconds during which the current has passed and by 0.001118.

In determining the constant of an instrument by this method, the current should be kept as nearly uniform as possible, and the readings of the instrument observed at frequent intervals of time. These observations give a curve from which the reading corresponding to the mean current (time-average of the current) can be found. The current, as calculated from the voltameter results, corresponds to this reading.

The current used in this experiment must be obtained from a battery, and not from a dynamo, especially when the instrument to be calibrated is an electrodynamometer.

SPECIFICATION B.—*The volt.*

Definition and properties of the cell.—The cell has for its positive electrode, mercury, and for its negative electrode, amalgamated zinc; the electrolyte consists of a saturated solution of zinc sulphate and mercurous sulphate. The electromotive force is 1.434 volts at 15° C., and between 10° C. and 25° C., by the increase of 1° C. in temperature, the electromotive force decreases by 0.00115 of a volt.

1. *Preparation of the mercury.*—To secure purity, it should be first treated with acid in the usual manner and subsequently distilled in vacuo.

2. *Preparation of the zinc amalgam.*—The zinc designated in commerce as "commercially pure" can be used without further preparation. For the preparation of the amalgam, 1 part by weight of zinc is to be added to 9 parts by weight of mercury, and both are to be heated in a porcelain dish at 100° C., with moderate stirring until the zinc has been fully dissolved in the mercury.

3. *Preparation of the mercurous sulphate.*—Take mercurous sulphate, purchased as pure; mix with it a small quantity of pure mercury, and wash the whole thoroughly with cold distilled water by agitation in a bottle; drain off the water and repeat the process at least twice. After the last washing, drain off as much of the water as possible. (For further details of purification, see Note A.)

4. *Preparation of the zinc sulphate solution.*—Prepare a neutral saturated solution of pure recrystallized zinc sulphate, free from iron, by mixing distilled water with nearly twice its weight of crystals of pure zinc sulphate and adding zinc oxide in the proportion of about 2 per cent by weight of the zinc sulphate crystals to neutralize any free acid. The crystals should be dissolved with the aid of gentle heat, but the temperature to which the solution is raised must not exceed 30° C. Mercurous sulphate, treated as described in 3, shall be added in the proportion of about 12 per cent by weight of the zinc sulphate crystals to neutralize the free zinc oxide remaining, and then the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

5. *Preparation of the mercurous sulphate and zinc sulphate paste.*—For making the paste, 2 or 3 parts by weight of mercurous sulphate are to be added to 1 by weight of

mercury. If the sulphate be dry, it is to be mixed with a paste consisting of zinc sulphate crystals and a concentrated zinc sulphate solution, so that the whole constitutes a stiff mass, which is permeated throughout by zinc sulphate crystals and globules of mercury. If the sulphate, however, be moist, only zinc sulphate crystals are to be added; care must, however, be taken that these occur in excess and are not dissolved after continued standing. The mercury must, in this case also, permeate the paste in little globules. It is advantageous to crush the zinc sulphate crystals before using, since the paste can then be better manipulated.

To set up the cell.—The containing glass vessel, * * * , shall consist of two limbs closed at the bottom and joined above to a common neck fitted with a ground-glass stopper. The diameter of the limbs should be at least two centimeters and their length at least 3 centimeters. The neck should be not less than 1.5 centimeters in diameter. At the bottom of each limb a platinum wire of about 0.4 millimeter diameter is sealed through the glass.

To set up the cell, place in one limb pure mercury and in the other hot liquid amalgam, containing 90 parts mercury and 10 parts zinc. The platinum wires at the bottom must be completely covered by the mercury and the amalgam, respectively. On the mercury place a layer 1 centimeter thick of the zinc and mercurous sulphate paste described in 5. Both this paste and the zinc amalgam must then be covered with a layer of the neutral zinc sulphate crystals 1 centimeter thick. The whole vessel must then be filled with the saturated zinc sulphate solution, and the stopper inserted so that it shall just touch it, leaving, however, a small bubble to guard against breakage when the temperature rises.

Before finally inserting the glass stopper it is to be brushed around its upper edge with a strong alcoholic solution of shellac and pressed firmly in place. (For details of filling the cell, see Note B.)

NOTES TO THE SPECIFICATIONS.

(A) *The mercurous sulphate.*—The treatment of the mercurous sulphate has for its object the removal of any mercuric sulphate which is often present as an impurity.

Mercuric sulphate decomposes in the presence of water into an acid and a basic sulphate. The latter is a yellow substance—turpeth mineral—practically insoluble in water; its presence, at any rate in moderate quantities, has no effect on the cell. If, however, it be formed, the acid sulphate is also formed. This is soluble in water and the acid produced affects the electromotive force. The object of the washings is to dissolve and remove this acid sulphate, and for this purpose the three washings described in the specification will suffice in nearly all cases. If, however, much of the turpeth mineral be formed, it shows that there is a great deal of the acid sulphate present, and it will then be wiser to obtain a fresh sample of mercurous sulphate, rather than to try by repeated washings to get rid of all the acid.

The free mercury helps in the process of removing the acid, for the acid mercuric sulphate attacks it, forming mercurous sulphate.

Pure mercurous sulphate, when quite free from acid, shows on repeated washing a faint yellow tinge, which is due to the formation of a basic mercurous salt distinct from the turpeth mineral, or basic mercuric sulphate. The appearance of this primrose-yellow tint may be taken as an indication that all the acid has been removed; the washing may with advantage be continued until this tint appears.

(B) *Filling the cell.*—After thoroughly cleaning and drying the glass vessel, place it in a hot-water bath. Then pass through the neck of the vessel a thin glass tube reaching to the bottom, to serve for the introduction of the amalgam. This tube

should be as large as the glass vessel will admit. It serves to protect the upper part of the cell from being soiled with the amalgam. To fill in the amalgam, a clean dropping tube about 10 centimeters long, drawn out to a fine point, should be used. Its lower end is brought under the surface of the amalgam, heated in a porcelain dish, and some of the amalgam is drawn into the tube by means of the rubber bulb. The point is then quickly cleaned of dross with filter paper, and is passed through the wider tube to the bottom and emptied by pressing the bulb. The point of the tube must be so fine that the amalgam will come out only on squeezing the bulb. This process is repeated until the limb contains the desired quantity of amalgam. The vessel is then removed from the water bath. After cooling, the amalgam must adhere to the glass, and must show a clean surface with a metallic luster.

For insertion of the mercury, a dropping tube with a long stem will be found convenient. The paste may be poured in through a wide tube reaching nearly down to the mercury and having a funnel-shaped top. If the paste does not move down freely it may be pushed down with a small glass rod. The paste and the amalgam are then both covered with the zinc sulphate crystals before the concentrated zinc sulphate solution is poured in. This should be added through a small funnel, so as to leave the neck of the vessel clean and dry.

For convenience and security in handling, the cell may be mounted in a suitable case, so as to be at all times open to inspection.

In using the cell, sudden variations of temperature should, as far as possible, be avoided, since the changes in electromotive force lag behind those of temperature.

Respectfully submitted.

Henry A. Rowland,
Chairman.
Henry L. Abbot,
George F. Barker,
Charles S. Hastings,
Albert A. Michelson,
John Trowbridge,
Carl Barus,
Committee.

LEGAL DEFINITION OF THE ELECTRICAL UNITS IN GREAT BRITAIN.

[Order in council, August 23, 1894.]

Whereas by "The Weights and Measures Act, 1889," it is, among other things, enacted that the Board of Trade shall from time to time cause such new denominations of standards for the measurement of electricity as appear to them to be required for use in trade to be made and duly verified;

And whereas it has been made to appear to the Board of Trade that new denominations of standards are required for use in trade, based upon the following units of electrical measurement, viz:

Ohm.

1. The ohm, which has the value 10^9 in terms of the centimeter and the second of time, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of a length of 106.3 centimeters.

Ampere.

2. The ampere, which has the value one-tenth in terms of the centimeter, the gram, and the second of time, and which is represented by the unvarying electric current, which, when passed through a solution of nitrate of silver in water, in accordance with the specification appended hereto and marked "A," deposits silver at the rate of 0.001118 of a gram per second.

Volt.

3. The volt, which has the value 10^8 in terms of the centimeter, the gram, and the second of time, being the electrical pressure that, if steadily applied to a conductor whose resistance is 1 ohm, will produce a current of 1 ampere, and which is represented by 0.6974 ($\frac{1000}{1434}$) of the electrical pressure at a temperature of 15° C. between the poles of the voltaic cell known as Clark's cell, set up in accordance with the specification appended hereto and marked "B."

And whereas they have caused the said new denominations of standards to be made and duly verified.

Now, therefore, Her Majesty, by virtue of the power vested in her by the said act, by and with the advice of Her Privy Council, is pleased to approve the several denominations of standards set forth in the schedule hereto as new denominations of standards for electrical measurement.

C. L. Peel.

SCHEDULE.

I.—Standard of Electrical Resistance.

A standard of electrical resistance denominated 1 ohm, being the resistance between the copper terminals of the instrument marked "Board of Trade Ohm Standard, verified 1894," to the passage of an unvarying electrical current when the coil of insulated wire forming part of the aforesaid instrument and connected to the aforesaid terminals is in all parts at a temperature of 15.4° C.

II.—Standard of Electrical Current.

A standard of electrical current donominated 1 ampere, being the current which is passing in and through the coils of wire forming part of the instrument marked "Board of Trade Ampere Standard, verified 1894," when on reversing the current in the fixed coils the change in the forces acting upon the suspended coil in its sighted position is exactly balanced by the force exerted by gravity in Westminster upon the iridio-platinum weight marked "A" and forming part of the said instrument.

III.—Standard of Electrical Pressure.

A standard of electrical pressure denominated 1 volt, being one-hundredth part of the pressure which, when applied between the terminals forming part of the instrument marked "Board of Trade Volt Standard, verified 1894," causes that rotation of the suspended portion of the instrument which is exactly measured by the coincidence of the sighting wire with the image of the fiducial mark A before and after application of the pressure, and with that of the fiducial mark B during the application of the pressure, these images being produced by the suspended mirror and observed by means of the eyepiece.

In the use of the above standards the limits of accuracy attainable are as follows:

For the ohm, within one-hundredth part of 1 per cent.

For the ampere, within one-tenth part of 1 per cent.

For the volt, within one-tenth part of 1 per cent.

The coils and instruments referred to in this schedule are deposited at the Board of Trade Standardising Laboratory, 8 Richmond Terrace, Whitehall, London.

SPECIFICATIONS REFERRED TO IN THE FOREGOING ORDER IN COUNCIL.

Specification A.

In the following specification the term silver voltameter means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment, and by noting this time the time average of the current, or if the current has been kept constant, the current itself can be deduced.

In employing the silver voltameter to measure currents of about 1 ampere the following arrangements should be adopted: The kathode on which the silver is to be deposited should take the form of a platinum bowl not less than 10 centimeters in diameter and from 4 to 5 centimeters in depth.

The anode should be a plate of pure silver some 30 square centimeters in area and 2 or 3 millimeters in thickness.

This is supported horizontally in the liquid near the top of the solution *by a platinum wire* passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling on to the kathode the anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

METHOD OF MAKING A MEASUREMENT.

The platinum bowl is washed with nitric acid and distilled water, dried by heat, and then left to cool in a desiccator. When thoroughly dry it is weighed carefully.

It is nearly filled with the solution and connected to the rest of the circuit by being placed on a clean copper support to which a binding screw is attached. This copper support must be insulated.

The anode is then immersed in the solution so as to be well covered by it and supported in that position; the connections to the rest of the circuit are made.

Contact is made at the key, noting the time of contact. The current is allowed to pass for not less than half an hour, and the time at which contact is broken is observed. Care must be taken that the clock used is keeping correct time during this interval.

The solution is now removed from the bowl and the deposit is washed with distilled water and left to soak for at least six hours. It is then rinsed successively with distilled water and absolute alcohol and dried in a hot-air bath at a temperature of about 160° C. After cooling in a desiccator it is weighed again. The gain in weight gives the silver deposited.

To find the current in amperes, this weight, expressed in grams, must be divided by the number of seconds during which the current has been passed, and by 0.001118.

The result will be the time average of the current, if during the interval the current has varied.

In determining by this method the constant of an instrument the current should be kept as nearly constant as possible, and the readings of the instrument observed at frequent intervals of time. These observations give a curve from which the reading corresponding to the mean current (time average of the current) can be found. The current, as calculated by the voltameter, corresponds to this reading.

SPECIFICATION B.—*On the preparation of the Clark cell.*

DEFINITION OF THE CELL.

The cell consists of zinc, or an amalgam of zinc with mercury, and of mercury in a neutral saturated solution of zinc sulphate and mercurous sulphate in water, prepared with mercurous sulphate in excess.

PREPARATION OF THE MATERIALS.

1. *The mercury.*—To secure purity it should be first treated with acid in the usual manner and subsequently distilled in vacuo.

2. *The zinc.*—Take a portion of a rod of pure redistilled zinc, solder to one end a piece of copper wire, clean the whole with glass paper or a steel burnisher, carefully removing any loose pieces of the zinc. Just before making up the cell dip the zinc into dilute sulphuric acid, wash with distilled water, and dry with a clean cloth or filter paper.

3. *The mercurous sulphate.*—Take mercurous sulphate, purchased as pure, mix with it a small quantity of pure mercury, and wash the whole thoroughly with cold distilled water by agitation in a bottle; drain off the water, and repeat the process at least twice. After the last washing, drain off as much of the water as possible.

4. *The zinc sulphate solution.*—Prepare a *neutral* saturated solution of pure ("pure recrystallized") zinc sulphate by mixing in a flask distilled water with nearly twice its weight of crystals of pure zinc sulphate, and adding zinc oxide in the proportion of about 2 per cent by weight of the zinc sulphate crystals to neutralize any free acid. The crystals should be dissolved with the aid of gentle heat, but the temperature to which the solution is raised should not exceed 30° C. Mercurous sulphate treated as described in 3 should be added in the proportion of about 12 per cent by weight of the zinc sulphate crystals to neutralize any free zinc oxide remaining, and the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

5. *The mercurous sulphate and zinc sulphate paste.*—Mix the washed mercurous sulphate with the zinc sulphate solution, adding sufficient crystals of zinc sulphate from the stock bottle to insure saturation, and a small quantity of pure mercury. Shake these up well together to form a paste of the consistence of cream. Heat the paste, but not above a temperature of 30° C. Keep the paste for an hour at this temperature, agitating it from time to time, then allow it to cool; continue to shake it occasionally while it is cooling. Crystals of zinc sulphate should then be distinctly visible, and should be distributed throughout the mass; if this is not the case, add more crystals from the stock bottle and repeat the whole process.

This method insures the formation of a saturated solution of zinc and mercurous sulphates in water.

TO SET UP THE CELL.

The cell may conveniently be set up in a small test tube of about 2 centimeters diameter and 4 or 5 centimeters deep. Place the mercury in the bottom of this tube, filling it to a depth of, say, 0.5 centimeter. Cut a cork about 0.5 centimeter thick to fit the tube; at one side of the cork bore a hole through which the zinc rod can

pass tightly; at the other side bore another hole for the glass tube which covers the platinum wire; at the edge of the cork cut a nick through which the air can pass when the cork is pushed into the tube. Wash the cork thoroughly with warm water, and leave it to soak in water for some hours before use. Pass the zinc rod about 1 centimeter through the cork.

Contact is made with the mercury by means of a platinum wire about No. 22 gauge. This is protected from contact with the other materials of the cell by being sealed into a glass tube. The ends of the wire project from the ends of the tube; one end forms the terminal, the other end and a portion of the glass tube dip into the mercury.

Clean the glass tube and platinum wire carefully, then heat the exposed end of the platinum red-hot, and insert it in the mercury in the test tube, taking care that the whole of the exposed platinum is covered.

Shake up the paste and introduce it without contact with the upper part of the walls of the test tube, filling the tube above the mercury to a depth of rather more than 1 centimeter.

Then insert the cork and zinc rod, passing the glass tube through the hole prepared for it. Push the cork gently down until its lower surface is nearly in contact with the liquid. The air will thus be nearly all expelled, and the cell should be left in this condition for at least twenty-four hours before sealing, which should be done as follows:

Melt some marine glue until it is fluid enough to pour by its own weight, and pour it into the test tube above the cork, using sufficient to cover completely the zinc and soldering. The glass tube containing the platinum wire should project some way above the top of the marine glue.

The cell may be sealed in a more permanent manner by coating the marine glue, when it is set, with a solution of sodium silicate, and leaving it to harden.

The cell thus set up may be mounted in any desirable manner. It is convenient to arrange the mounting so that the cell may be immersed in a water bath up to the level of, say, the upper surface of the cork. Its temperature can then be determined more accurately than is possible when the cell is in air.

In using the cell sudden variations of temperature should as far as possible be avoided.

The form of the vessel containing the cell may be varied. In the H form the zinc is replaced by an amalgam of 10 parts by weight of zinc to 90 of mercury. The other materials should be prepared as already described. Contact is made with the amalgam in one leg of the cell, and with the mercury in the other, by means of platinum wires sealed through the glass.

LEGAL DEFINITION OF THE ELECTRICAL UNITS IN CANADA.

[Assented to July 23, 1894, 57–58 Vict., c. 38.]

Her Majesty, by and with the advice and consent of the Senate and House of Commons of Canada, enacts as follows:

1. This act may be cited as *The Electrical Units Act.*

2. The units of electrical measure for Canada shall be the following:

(*a*) As a unit of resistance, the ohm, which is based upon the ohm equal to 10^9 units of resistance of the centimeter-gramme-second system of electro-magnetic units, and is represented by the resistance offered

Ohm.

to an unvarying electric current by a column of mercury, at the temperature of melting ice 14.4521 grammes in mass, of a constant cross-sectional area and of the length of 106.3 centimeters.

Ampere.

(*b*) As a unit of current, the ampere, which is one-tenth of the unit of current of the centimeter-gramme-second system of electro-magnetic units, and is represented sufficiently well for practical use by the unvarying current, which, when passed through a solution of nitrate of silver in water, and in accordance with the specification contained in schedule 1 to this act, deposits silver at the rate of 0.001118 of a gramme per second.

Volt.

(*c*) As a unit of electromotive force, the volt, which is the electromotive force that, steadily applied to a conductor whose resistance is 1 ohm, will produce a current of 1 ampere, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the electromotive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° centigrade and prepared in accordance with the specification contained in schedule 2 to this act.

Coulomb.

(*d*) As a unit of quantity, the coulomb, which is the quantity of electricity transferred by a current of 1 ampere in one second.

Farad.

(*e*) As a unit of capacity, the farad, which is the capacity of a condenser charged to a potential of 1 volt by 1 coulomb.

Joule.

(*f*) As a unit of work, the joule, which is equal to 10^7 units of work in the centimeter-gramme-second system, and is represented sufficiently well for practical use by the energy expended in one second by 1 ampere in 1 ohm.

Watt.

(*g*) As a unit of power, the watt, which is equal to 10^7 units of power in the centimeter-gramme-second system, and is represented sufficiently well for practical use by the work done at the rate of 1 joule per second.

Henry.

(*h*) As a unit of induction, the henry, which is the induction in a circuit when the electro-motive force induced in that circuit is 1 volt, while the inducing current varies at the rate of 1 ampere per second.

3. The units of electrical measure described in the next preceding section, or such standard apparatus as is necessary to produce them, shall be deposited in the Department of Inland Revenue and shall form part of the system of standards of measure and weight established by *The Weights and Measures Act.*

SCHEDULE ONE.

In the following specification, the term silver voltameter means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment; and by noting this time, the time average of the current, or, if the current has been kept constant, the current itself, can be deduced.

In employing the silver voltameter to measure currents of about 1 ampere, the following arrangements should be adopted: The cathode on which the silver is to be deposited should take the form of a platinum bowl not less than 10 centimeters in diameter and from 4 to 5 centimeters in depth. The anode should be a plate of pure silver 30 square centimeters in area and 2 or 3 millimeters in thickness. This is supported horizontally in the liquid near the top of the solution by *a platinum wire* passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling onto the cathode, the

anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

SCHEDULE TWO.

The cell consists of zinc and mercury in a saturated solution of zinc sulphate and mercurous sulphate in water, prepared with mercurous sulphate in excess, and is conveniently contained in a cylindrical glass vessel.

The mercury.—To secure purity it should be first treated with acid in the usual manner, and subsequently distilled in vacuo.

The zinc.—Take a portion of a rod of pure redistilled zinc, solder to one end a piece of copper wire, clean the whole with glass paper, carefully removing any loose pieces of the zinc. Just before making up the cell dip the zinc into dilute sulphuric acid, wash with distilled water, and dry with a clean cloth or filter paper.

The zinc sulphate solution.—Prepare a saturated solution of pure ("pure recrystallized") zinc sulphate by mixing in a flask distilled water with nearly twice its weight of crystals of pure zinc sulphate, and adding zinc oxide in the proportion of about 2 per cent by weight of the zinc sulphate crystals to neutralize any free acid. The crystals should be dissolved with the aid of gentle heat, but the temperature to which the solution is raised should not exceed 30° C. Mercurous sulphate treated as hereinafter described should be added in the proportion of about 12 per cent by weight of the zinc sulphate crystals and the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

The mercurous sulphate.—Take mercurous sulphate, purchased as pure, and wash it thoroughly with cold distilled water by agitation in a bottle; drain off the water, and repeat the process at least twice. After the last washing, drain off as much of the water as possible.

Mix the washed mercurous sulphate with the zinc-sulphate solution, adding sufficient crystals of zinc sulphate from the stock bottle to insure saturation, and a small quantity of pure mercury. Shake these up well together to form a paste of the consistence of cream. Heat the paste, but not above a temperature of 30° C. Keep the paste for an hour at this temperature, agitating it from time to time, then allow it to cool, continuing to shake it occasionally while cooling. Crystals of zinc sulphate should then be distinctly visible, and should be distributed throughout the mass. If this is not the case, add more crystals from the stock bottle, and repeat the whole process. This method insures the formation of a saturated solution of zinc and mercurous sulphates in water.

Contact is made with the mercury by means of a platinum wire about No. 22 gauge. This is protected from contact with the other materials of the cell by being sealed in a glass tube. The ends of the wire project from the ends of the tube; one end forms the terminal; the other end and a portion of the glass tube dip into the mercury.

LEGAL DEFINITION OF THE ELECTRICAL UNITS IN GERMANY.

[Law of June 1, 1898, R. G. Bl., p. 905.]

SECTION 1. The legal units for electrical measurements are the ohm, ampere, and volt.

SEC. 2. The unit of electrical resistance is the ohm. It is represented by the resistance of a column of mercury, at the temperature of melting ice, of uniform cross section, practically equivalent to 1 square millimeter, of a length of 106.3 centimeters, and of a mass of 14.4521 grammes.

Ohm.

SEC. 3. The unit of current is the ampere. It is represented by the unvarying electric current which in passing through an aqueous solution of silver nitrate deposits in one second 0.001118 grammes of silver.

Ampere.

SEC. 4. The unit of electro-motive force is the volt. It is represented by the electro-motive force which when applied to a conductor having a resistance of 1 ohm produces a current of 1 ampere.

Volt.

SEC. 5. The Bundesrath is empowered—

(*a*) To fix the conditions under which the silver is to be deposited, in the definition of the ampere. (Sec. 3.)

(*b*) To fix designations for the units of electric quantity, energy, power, capacity, and inductance.

(*c*) To prescribe designations for the multiples and submultiples of the electrical units.

(*d*) To fix the manner in which the strength, electro-motive force, energy, and power of alternating currents is to be calculated.

SEC. 6. According to this paragraph instruments used in the measurement of electrical power for commercial purposes must have their indications based on the legal units. The use of incorrect measuring instruments is prohibited. The Bundesrath is empowered to fix the limits of tolerance for such apparatus, after giving a hearing to the Physikalisch-Technische Reichsanstalt.

The Bundesrath is empowered to issue regulations concerning the official verification and periodic reverification of measuring apparatus.

SEC. 7. The Physikalisch-Technische Reichsanstalt is directed to construct primary mercurial resistance standards and assume responsibility for their control and safe custody at different places. It is also to reverify the resistance of standards of solid metals used in the intercomparisons by an annual recomparison with the mercurial standards.

SEC. 8. The Physikalisch-Technische Reichsanstalt is to provide for the issue of officially certified standard resistances and standard cells for the measurement of current and electro-motive force.

SEC. 9. The official testing and certification of electrical measuring instruments shall be carried out by the Physikalisch-Technische Reichsanstalt. The Imperial Chancellor may intrust this authority elsewhere. All standards and measuring apparatus employed in official verifications must be certified to by the Physikalisch-Technische Reichsanstalt.

SEC. 10. The Physikalisch-Technische Reichsanstalt is to assume the responsibility that the official testing and verification of electrical measuring apparatus in the German Empire shall be made in a uniform manner. It is to assume the technical supervision of the inspection service, and to prescribe all technical specifications concerning the same. It is especially to determine what kind of measuring instru-

ments shall be admitted to official verification, to adopt regulations concerning the material, construction, or designation of the apparatus, to regulate the methods employed in the testing and verification, and to fix the fees and specify the seal to be employed.

Sec. 11. Measuring apparatus verified in accordance with this law may be used in trade in any part of the Empire.

Sec. 12. Whoever, engaged in the industrial supply of electrical energy, does not comply with section 6, or the regulations based thereon, will be subjected to a fine not exceeding 100 marks, or imprisonment not to exceed four weeks. In addition, the incorrect instruments, or the instruments not complying with the regulations, shall be subject to seizure.

Sec. 13. This law and the regulations adopted in accordance with sections 6 and 12 shall take effect January 1, 1902; the remainder on the date of its promulgation.

REGULATIONS FOR CARRYING OUT THE LAW; ISSUED BY THE BUNDESRATH.

[Reichsgesetzblatt No. 16, 1901, June 1, 1898.]

In accordance with paragraph 5 of the law defining the electrical units of measurement (Reichsgesetzblatt, p. 905), the following specifications are adopted:

1. *Conditions under which the silver is to be deposited in the specification of the ampere.* (Sec. 5 a).—The solution shall consist of from 20 to 40 parts by weight of pure silver nitrate in 100 parts of distilled water free from chlorine. It shall not be used after 3 grammes of silver are deposited from 100 cubic centimeters of solution.

All parts of the anode in contact with the solution shall consist of pure silver. The cathode shall consist of platinum. When the deposited silver exceeds 0.1 gramme per square centimeter the silver is to be removed.

The current density at the anode shall not exceed one-fifth, and at the cathode one-fiftieth ampere per square centimeter.

Before weighing, the cathode is first to be rinsed with distilled water free from chlorine until the addition of a drop of hydrochloric acid to the wash water produces no opalescence. The cathode is then to be soaked for ten minutes in distilled water at 70° to 90° C., and is to be finally washed with distilled water. The last wash water after cooling must not become opalescent upon the addition of hydrochloric acid. The cathode is dried by the aid of heat and kept in a desiccator until it is weighed, which shall not be done less than ten minutes after cooling off.

2. *Designation of the electrical units* (*sec. 5b*).—(*a*) The quantity of electricity flowing through the cross section of a conductor in one second when the current in the same is equal to 1 ampere is called an ampere-second (coulomb), and the quantity flowing in one hour an ampere hour.

(*b*) The power corresponding to an ampere in a conductor having a potential difference of 1 volt between its terminals is called a watt.

(*c*) The work done in one hour when the power is equal to 1 watt is called a watt hour.

(*d*) The capacity of a condenser which is charged by an ampere-second to 1 volt is called a farad.

(*e*) The self-inductance of a conductor in which 1 volt is induced by a uniform change in the current of 1 ampere per second is called a henry.

3. *Designations for the multiples and submultiples of the electrical units* (*sec. 5c*).—The following prefixes to the name of a unit shall have the following meanings:

Kilo	1,000 times
Mega (meg)	1,000,000 times
Milli	One one-thousandth
Micro (mikr)	One-millionth

EXPLANATION OF THE SPECIFICATIONS. (SEC. 5a.)

1. On account of its fundamental importance in defining unit current, the silver voltameter must be employed under prescribed conditions in order that the amount of silver deposited will give the correct value for the current measured. In this connection the fact is to be considered that the silver solution gradually experiences a yet unexplained change by the long-continued passage of an electric current, by which small variations in the amount of silver deposited are produced. Moreover, in order to obtain compact deposits of silver the concentration of the solution and the current density at the electrodes must be confined within certain limits. Finally, on account of the sensitiveness of the silver solution to impurities it appeared necessary to prescribe regulations concerning the water employed in washing, and in order to weigh only the deposited silver to specify the manner of washing.

In these specifications the experiences of the most reliable experimenters have been considered. They may be considered not only entirely sufficient for their purpose, but in addition they are possibly somewhat too rigorous for practical needs. Since, however, it is really not necessary, except in rare cases, to refer current measurements to the silver voltameter, as much simpler methods are available, the specifications could be rigorously drawn.

LEGAL DEFINITION OF THE ELECTRICAL UNITS IN AUSTRIA.

[Ordinance No. 176, Ministry of Commerce, of July 4, 1900. Concerning the testing and certifying of electrical supply meters.]

The electrical units are derived from the fundamental metrical units of length, mass, and time, according to the electro-magnetic system of measurement, taking the centimeter as the unit of length, the gramme as the unit of mass, and the mean solar second, of which there are 86,400 in a mean solar day, as the unit of time. The resulting units are designated as units of the c. g. s. electro-magnetic system (centimeter-gramme-second system).

Ohm.

The unit of resistance is the ohm, which is equal to 10^9 units of resistance of the electro-magnetic c. g. s. system. For commercial purposes the ohm may be considered equal to the resistance offered to an unvarying current by a column of mercury having a mass of 14.4521 grammes, a length of 106.3 centimeters, at the temperature of melting ice. (No reference is made to a uniform cross section of the mercurial column.)

Ampere.

The unit of current is the ampere, which is equal to the one-tenth part of the electro-magnetic unit of current of the c. g. s. system. For commercial purposes the ampere may be considered equal to the value of an unvarying current which when passing through an aqueous solution of silver nitrate deposits 0.001118 gramme silver per second.

Volt. The unit of electromotive force is the volt, which is equal to that electromotive force which acting steadily on a conductor having a resistance of 1 ohm produces in the same a current of 1 ampere.

Watt. The unit of power is the watt, which is equal to 10^7 units of power of the c. g. s. system, or equal to the power corresponding to a current of 1 ampere at an electromotive force of 1 volt (voltampere).

Coulomb. The coulomb is equal to the quantity of electricity flowing in one mean solar second through a conductor carrying a current of 1 ampere. One ampere-hour corresponds to 3,600 coulombs.

Watthour. The work done in 3,600 seconds in a conductor in which the power is 1 watt is equal to 1 watthour. One hundred watthours are equal to 1 hectowatthour. One thousand watthours are equal to 1 kilowatthour.

LEGAL DEFINITION OF THE ELECTRICAL UNITS IN FRANCE.

[Decree of the President, April 25, 1896.]

Ohm. The unit of electrical resistance—the ohm—is the resistance offered to an unvarying current by a column of mercury at a temperature of melting ice, having a mass of 14.4521 grammes, a constant cross section, and a length of 106.3 centimeters.

Ampere. The unit of current—the ampere—is the one-tenth of the electro-magnetic unit of current. It is represented sufficiently well for practical purposes by the unvarying current which deposits in one second 0.001118 grammes of silver.

Volt. The unit of electro-motive force—the volt—is the electro-motive force which produces a current of 1 ampere in a conductor having a resistance of 1 ohm. It is represented sufficiently well for practical purposes by 0.6974, or ($\frac{1000}{1434}$) of the electro-motive force of the Latimer Clark cell.

SPECIFICATIONS FOR THE SILVER VOLTAMETER.

The specifications for the silver voltameter are the same as those adopted by the Chicago congress, with the exception that the anode is to be supported by a silver rod instead of platinum wires, the latter having been found to be a source of variations. In addition, the directions for making a measurement are the same as those given in the English law.

SPECIFICATIONS FOR THE STANDARD CELL.

The specifications for the standard cell are the Board of Trade specifications, which are legalized in England.

PROPOSED LAW DEFINING THE ELECTRICAL UNITS FOR USE IN BELGIUM.

There is established for the Kingdom a single system of electrical units having as its base the ohm, the ampere, and the volt.

The ohm is the resistance offered to an unvarying current, by a column of mercury at the temperature of melting ice, having a mass of 14.4521 grammes, a constant cross section, and a length of 106.3 centimeters.

Ohm.

The ampere is represented sufficiently well for practical purposes by the intensity of a constant current which precipitates in one second 0.001118 grammes of silver from an aqueous solution of silver nitrate.

Ampere.

The volt is represented by the electro-motive force which produces a current of 1 ampere in a conductor of which the resistance is 1 ohm.

Volt.

The denominations of the derived electrical units, especially the units of energy and power, shall be fixed by royal decree. Multiples and submultiples of the legal units may likewise be fixed.

Derived units.

Within two years after the promulgation of the law practical standards in conformity with the legal system of units shall be established by a special commission named by the King.

The custody and periodic verification of these standards shall be entrusted to the minister of industry and labor.

PROPOSED LAW DEFINING THE ELECTRICAL UNITS IN SWITZERLAND.

The law proposed by the Swiss Electro-Technische Verein, and drawn up by the president of the commission on inspection service and units of measurement, is substantially the same as the German law.

OTHER COUNTRIES.

In Mexico no electrical units have been legalized, but a bill is under consideration defining the electrical units, which at the suggestion of the Bureau of Standards will be so worded that any modifications adopted at St. Louis may be made.

In Norway, Sweden, Denmark, Netherlands, Portugal, Italy, Japan, and Russia no units have been legalized.

No definite information has been obtained from Spain.